ETV Verification Protocol
Danfoss AK-CC Controllers

DTI Refrigeration and Heat Pump Technology
J.no. 1001
Test no. 1 – Reduced energy consumption

Version 4.3

1 Table of contents

2 Introduction

Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application, under defined conditions and quality assurance.

DANETV is a Danish center for verification of environmental technology.

This protocol describes the framework for the verification of the technology product and provides information required for the Test plan.

2.1 Name of the product

The product is the Danfoss AK-CC Controller Series

2.2 Name and contact of vendor

Danfoss A/S, Nordborgvej 81, 6430 Nordborg, Denmark
Contacts:

Frede Schmidt (R&D Engineer) +45 7488 1553,
e-mail : frs@danfoss.com

Peter Eriksen (R&D Director) +45 7488 4191,
e-mail: peter_eriksen@danfoss.com

2.3 Name of center/verification responsible

Danish Technological Institute, Verification Center - Refrigeration and Heat Pump Technology, building 14, Kongsvangs alle 29, DK-8000, Aarhus, Denmark.

Verification responsible:

Bjarke Paaske (BJPA) +45 7220 2037,
e-mail: bjpa@teknologisk.dk

Internal reviewer:

Anders Mønsted (ANMD) +45 7220 2273,
e-mail: anmd@teknologisk.dk

2.4 Verification and test organization

The verification will be conducted by Danish Technological Institute. The test organization is shown in figure 1.

The verification is planned and conducted to satisfy the requirements of the ETV scheme currently being established by the European Union (EU ETV).

Verification and tests will be performed by Danish Technological Institute under DANETV under contract with Danfoss A/S.

The day to day operations of the verification and tests will be coordinated and supervised by DTI personnel, with the participation of the vendor, Danfoss A/S.

The testing will be conducted at the Danish Technological Institute, Kongsvang Allé, 8000 Århus C.

DTI test center test sub-body will perform all samplings during the verification.

DTI test center will operate the Danfoss system manager according to instructions given by Danfoss A/S. Danfoss A/S will assist when necessary as described in the contract.

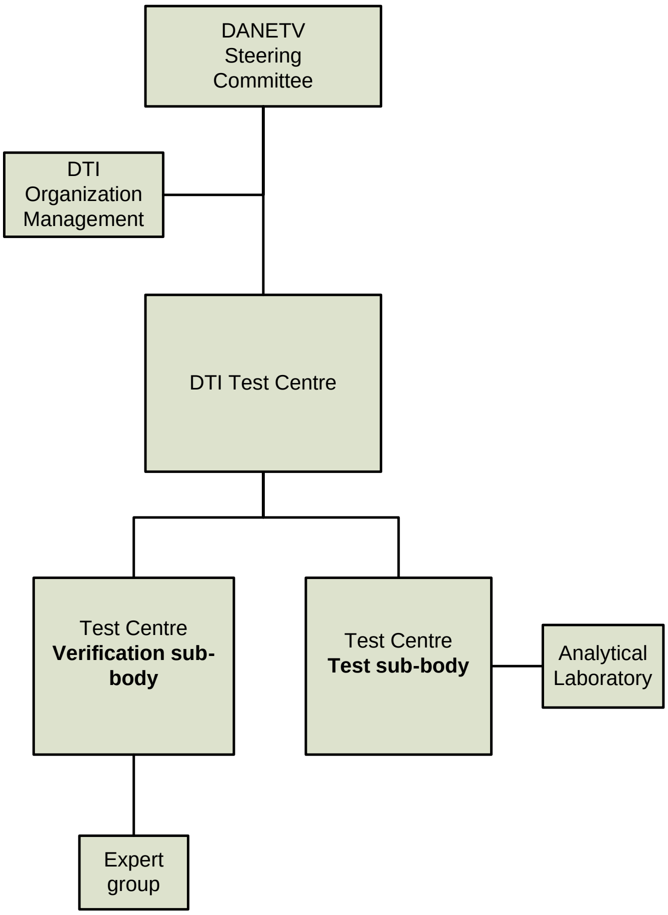

Figure 1 - Verification organization

Table 1 - Responsible personnel in test organization

Unit in test organization	**Responsible**
DTI Dan ETV steering committee member	Lars Jøker
DTI organization management Refrigeration and Heat Pump Technology	Claus S. Poulsen
DTI Refrigeration and Heat Pump Technology, Verification sub-body	Bjarke Paaske
DTI Refrigeration and Heat Pump Technology, Test sub-body	Klaus Frederiksen

2.5 Expert group

The expert group assigned to this verification and responsible for review of the verification plan and report documents includes:

Brian Elmegaard (BE) +45 4525 4169,
e-mail: be@mek.dtu.dk

2.6 Verification process

Verification and tests will be conducted in two separate steps, by the verification sub-body and the test sub-body respectively.

The verification sub-body is responsible for preparation and compilation of the verification protocol and the test report.

The test sub-body is responsible for the test plan and the test report.

The steps in the verification are shown in figure 2.

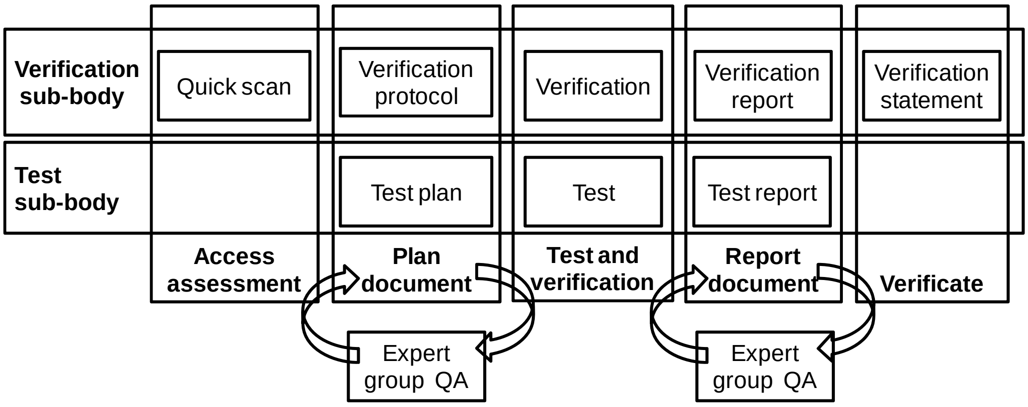

Figure 2 - Verification steps

A DANETV verification statement will be issued after completion of the verification.

3 Description of the technology

This verification process concern two energy reducing features in Danfoss AK-CC controllers. One feature is automatic adaptation of rail heat. The other is adaptation of defrost sessions. The necessity of both rail heat and defrost depends on the current humidity level of the surrounding air.

Rail heat

Freezing and cooling display cabinets in retail stores are provided with electrical heaters in rails and windows. Rail heat keeps the temperature of rails and windows above the dew point and hereby prevents condensate on the outer surfaces of the cabinets.

The amount of rail heat necessary depends on the current dew point of the ambient air. In existing systems rail heat is provided at a constant level. The level is often set to cope with high dew point temperatures at the worst possible conditions.

In order to avoid excessive energy consumption Danfoss AK-CC controller adapts rail heat according to the current dew point. Danfoss system managers monitor relative humidity and temperature of the surrounding air. From these parameters the system manager calculates the dew point and provides the current value to all controllers in the system. Each controller will then adjust the amount of rail heat individually to the cabinets and maintain a surface temperature just above the dew point.

The surface temperature of the cabinets is linear related to the power consumption of the heaters. As different cabinets have different characteristics both slope and starting point of the linear curve may vary. Some of the parameters that will affect the characteristics are design of the cabinet, power of electrical heaters, temperature inside the cabinet etc.

The controller is provided with characteristics of a specific cabinet through data given by the user. The user must provide the controller with two points on the curve. From these the controller will know the characteristics of the cabinet and hereby be able to adjust the rail heat according to the need of a particular cabinet.

Figure 3 shows the lowest surface temperature of a specific cabinet according to the amount of rail heat provided.

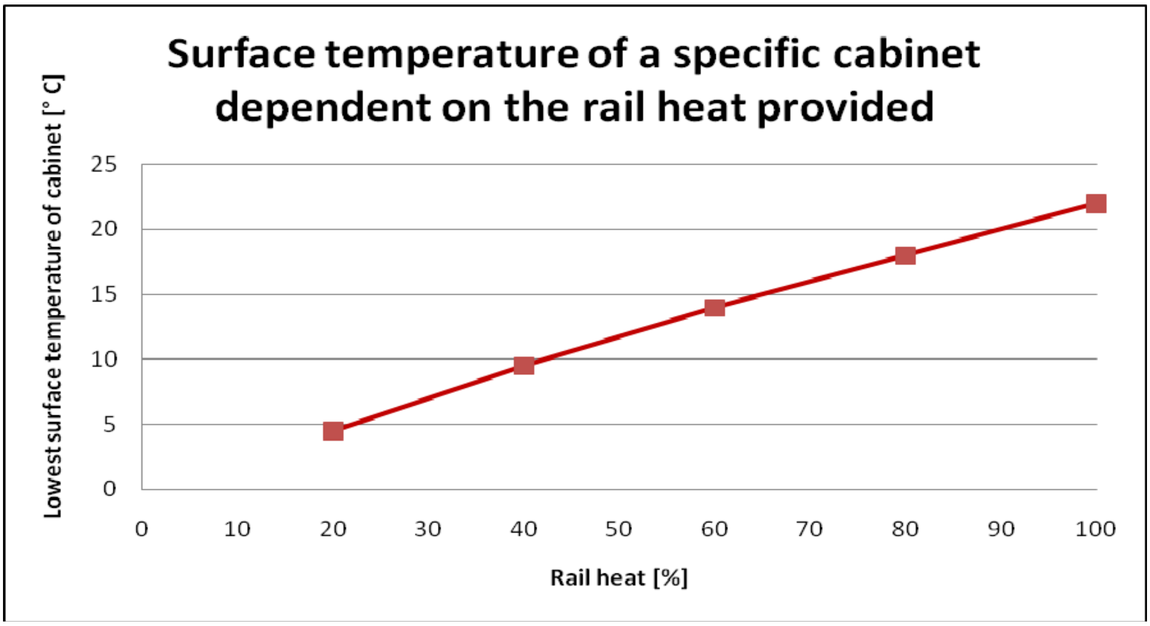

Figure 3 - Surface temperature is linear related to the amount of rail heat provided

Defrost sessions

Apart from electrical heaters at the rail heat system, the cabinets are fitted with electrical heaters at evaporators to melt any ice formations (defrost). Moist from the air will turn to frost as air passes the cold evaporators. Frost sticks to cold surfaces and during time frost will block up the evaporator and cause a stop of the cooling process.

To prevent this, defrost sessions are initiated on a regular basis according to a defined schedule. As the build up of frost depends both on the moist level of the current ambient air and on the rate of door openings, the necessity of defrost sessions varies and defrost is often initiated unnecessarily.

Danfoss AK-CC controllers are able to monitor ice frost formations and apply defrost sessions according to the current conditions. The controller calculates airflow through the evaporator by monitoring the cooling capacity. As frost builds up on the evaporator, air flow is reduced and the controller initiates a defrost session.

The controller is able to monitor the cooling capacity through existing sensors in the system. The different sensors of the system are shown in figure 4.

Application example

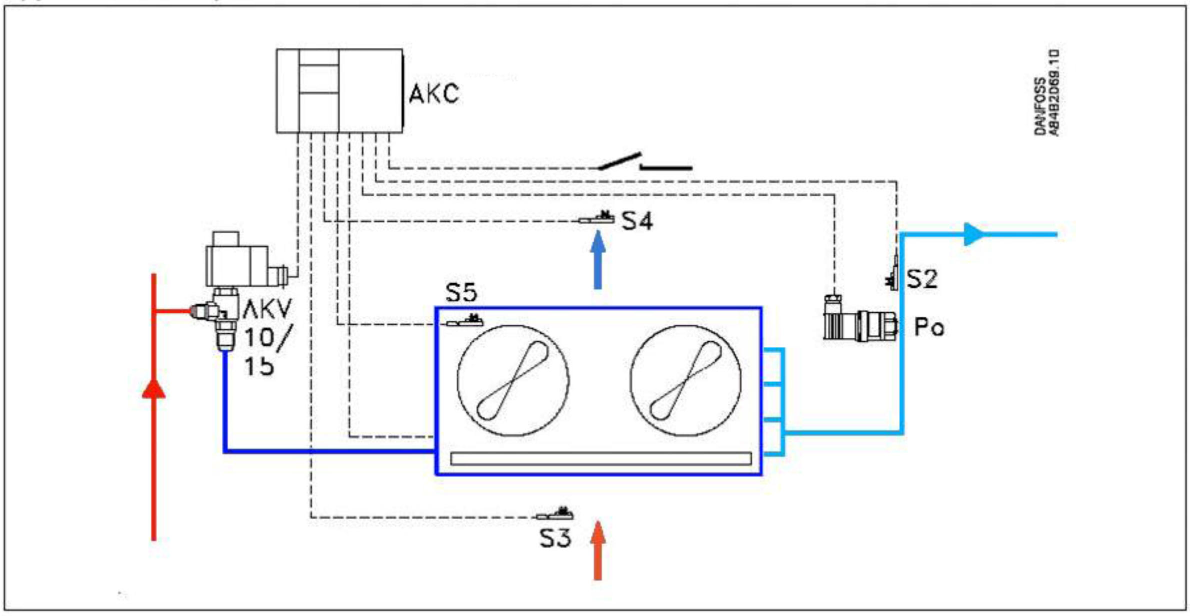

Figure 4 - Example of components and sensors

As shown on figure 4, the controller receives data from four temperature sensors (S2 – S5). Apart from temperature sensors, AK-controllers are connected to two pressure sensors. One at the low pressure side (P0), and one at the high pressure side (not shown).

The controller measures superheat at the evaporator and supply refrigerant through an AKV expansion valve accordingly. The controller is able to calculate the refrigerant mass flow from the pressure difference and opening degree of the expansion valve.

Enthalpy increase of the refrigerant is calculated using the pressure (P0) and the temperature of the superheated refrigerant (S2). The cooling capacity (Q_{ref}) of the evaporator equals the massflow of refrigerant (m_{ref}) multiplied by the enthalpy increase Δh_{ref}:

$$Q_{ref} = m_{ref} \cdot \Delta h_{ref}$$

The cooling capacity of the refrigerant equals that of the air passing the evaporator. The cooling capacity of the air Q_{air} is calculated by the volume flow V_{air} and enthalpy decrease of the air passing the evaporator. As the pressure loss through the evaporator is negligible, the enthalpy difference is correlated to the temperature difference Δt_{air} of the air passing the evaporator:

$$Q_{air} = V_{air} \cdot \Delta t_{air}$$

The cooling capacity of the refrigerant equals that of the air and the following relation is valid:

$$Q_{air} = Q_{ref}$$

$$\Updownarrow$$

$$V_{air} \cdot \Delta t_{air} = m_{ref} \cdot \Delta h_{ref}$$

$$\Updownarrow$$

$$V_{air} = \frac{m_{ref} \cdot \Delta h_{ref}}{\Delta t_{air}}$$

The controller monitors both massflow of refrigerant, enthalpy increase of the refrigerant and temperature difference of the air. Because of this the controller is able to calculate the current air flow at all time.

Whenever the controller is switched to adaptive defrost, it initiates a defrost session instantly. Right after a defrost session the controller calculates the current airflow. As there is no frost at the evaporator at this point, the calculated airflow is the maximum flow possible of the system. The value of the maximum airflow is then used as a reference value of the system.

During operation of the cabinet the current airflow of the evaporator is regularly calculated and compared to the reference value. If the current airflow drops to a certain value, the evaporator has reached a critical level of frost at the surfaces and a defrost session is initiated.

4 Description of the product

AK-CC controllers are complete refrigeration appliance controllers for a great number of different refrigeration appliances and cold store rooms.

The controller is an electronic unit that controls the different functions of a cooling application. In applications with cooling and freezing cabinets the main functions of the controller are: liquid injection of refrigerant in evaporators, monitoring of superheat, defrosting of evaporators, rail heat, control of compressors, control of night blinds and control of lights.

A single controller is able to operate up to four evaporators. Larger and more complex systems consist of several controllers managed through an overall system unit called a “system manager”. Danfoss system managers are able to monitor alarms and data logging of decentral refrigeration system. More System Managers can be applied by means of IP connections, in order to register measurements from up to 400 controllers. Remote operation is available through modem connection or an IP network.

Rail heat

The AK-CC controller is able to operate rail heat either as fully on, using a timer or adaptive. In “Timer” mode the controller pulse rail heat to reduce energy consumption. Rail heat is pulsed according to a time interval and percentage defined by the user. A common used time interval is 10 minutes with a percentage of 80 %. This setting means that the controller will switch on rail heat for 8 minutes and off for 2 minutes repeatedly. The controller is able to use different night and day settings as the dew point usually drops during closing hours. A common used setting on freezing cabinets in Danish retail stores is 80 % rail heat during day time and 30 % during night time.

Defrost

AK-CC controller can initiate a defrost session of the evaporators in a number of different ways. In general defrost is either done naturally, by hot gas or electrical heaters.

Natural defrost is possible in cooling cabinets with an air temperature above the freezing point. By shutting off the refrigerant supply at the evaporator and keep the fans running, heat from the surrounding air will gradually melt frost at the evaporator.

Hot gas defrost are used on systems where it is possible to reroute the refrigeration circuit, so that the refrigerant gas exiting the compressor at high pressure and temperature, enters the evaporator directly. The refrigerant circuit is inverted by extra piping and solenoid valves. In systems at retail stores with remote condensing units, hot gas defrost will cause excessive piping and increase the system cost considerable. Because of this, hot gas defrost is not used in retail stores.

AK-CC controllers are able to perform electrical defrost sessions in a number of different ways:

- Interval: Defrost is started at fixed time intervals, for instance every eight hours.
- Refrigeration time: Defrost is started at fixed refrigeration time intervals, in other words, a low need for refrigeration will ”postpone” the defrost.
- Schedule: At this setting defrost is started at fixed times of the day and night. However, max. 6 times.
- Contact: Defrost is started with a contact signal on a digital input.
- Network: The signal for defrost is received from a system unit via the data communication.
- Manual: An extra defrost can be activated from the controller’s lower-most button
- Adaptive defrost: Defrosting is started based on intelligent registering of evaporator performance as described above.

The mentioned methods can be used at random. A defrost session is ended either by a predefined timer or a temperature sensor at the evaporator. As the temperature exceeds a certain value (defined by the user), all frost is melted.

The commonly used settings in Danish retail stores are scheduled sessions stopped by a temperature sensor.

5 Application and performance parameter definitions

5.1 Matrix/matrices

The matrix is the type of material the product is intended for.

The matrix of the application is freezing/cooling cabinets in retail stores.

5.2 Target(s)

A target is defined as the property affected by the product

The target of the product is:

- Optimized control of rail heat and defrost sessions.
- The power of the rail heat system will adapt according to the surrounding air temperature and humidity and keep the rail temperature a few degrees above the dew point at all time.
- Frost formations are monitored and the system will only initiate defrost sessions when needed.

5.3 Effects

The effects are described as the way the target is affected

The effects of this application are:

1: Reduced energy consumption – both directly at the heaters and indirectly at the cooling system.

2: Reduced mean temperatures of the cooled products.

5.4 Performance parameters for verification

The ranges of performance relevant for the application, as derived in Appendix 3, are presented below. These ranges are used for planning the verification and testing only.

Concerning energy consumption of both heaters and cooling system the following parameters must be measured:

- Overall energy consumption of the freezing cabinet
- Energy consumption of rail heat
- Energy consumption of defrost
- Mass flow of refrigerant at evaporator
- Temperature of refrigerant liquid line
- Temperature of refrigerant at evaporator outlet
- Pressure at evaporator outlet

Other performance parameters that are measured include:

- Temperature in test packages
- Visually inspection of moist at rails during the test

All parameters are measured according to ISO 23953 /5/

5.5 Additional parameters

Besides the performance parameters to be obtained by testing, compilation of parameters describing user manual and occupational health & safety issues of the product are required as part of the verification.

6 Existing data

6.1 Summary of existing data

Previous work has shown great potential of adaptive rail heat and defrosts systems. Throughout experiments, energy consumption and temperature of systems using both default and manually adapted settings have been compared. Both energy consumption and mean temperature of the products is significantly improved by adjusting the rail heat according to demand. It is also clear that the temperature during defrost will rise dramatically, and optimized defrost sessions will reduce both energy consumption and mean temperature of the products.

So far adaptive control systems have not been tested. All experiments are carried out, by manually adjusting the heat according to demand. The previous experiments proof the benefits of only applying the amount of heat necessary, and show the importance of automatic adaptive system managers.

6.2 Quality of existing data

Documentation of previous experiments exists, but the experiments were not executed using adequate equipment in a controlled environment.

6.3 Accepted existing data

Data from previous experiments is not usable for this verification process.

7 Test plan requirements

7.1 Test design

The performance test will consist of two similar test series showing the performance of a standard freezing cabinet. One test series will be carried out using default settings on rail heat and defrost. The other series will be carried out the adaptive functions of the controller. The effect of the adaptive function is verified by comparing the results.

The performance test is based on the existing European Standard ISO 23953 /5/, with some exceptions. ISO 23953 is the standard performance test for freezing cabinets, showing both power consumption and cooling ability of different types of freezing and cooling cabinets. It is important to notice that ISO 23953 is a performance test of the cabinet – not the controller. By performing several performance tests using both adaptive and standard control settings, the effect of adaptive control will show through the performance of the cabinet. The standard control settings used, must correspond to typical settings of the specific type of cabinet and ambient conditions (test matrix) as tested in the verification process. The standard settings used, are stated in the Test Plan and Test Report chapter 3.5.5.

Ambient temperature and humidity during the tests will not follow the climate classes given by ISO 23953. The performance will be measured using a test matrix of 24 hour tests, using different ambient settings to reflect actual conditions in retail stores in

Denmark. The matrix is based on Danish DRY-data (dimensional reference year) /6/ and ISO 13788 – Annex A (internal humidity loads) /7/.

As the effect of the product will vary significant dependent on ambient conditions, it is important to do several tests and hereby calculate the average annual effect.

The total electrical energy consumption (TEC) of the display cabinet is divided into direct electrical energy consumption (DEC) and refrigeration electrical energy consumption (REC).

DEC is the consumption of all electrical components in the cabinet – ventilation, rail heat, defrost etc. DEC is measured at the power supply and reported in kWh per 24-hour test period.

REC is the electrical energy consumption due to cooling of the cabinet. Because the refrigerant is supplied by remote condensing systems, it is not possible to measure the REC directly on the power supply. REC is determined by measuring the heat extraction in the cabinet, and recalculating into electrical energy consumption.

Heat extraction is measured through mass flow and enthalpy increase in the refrigerant. Enthalpy increase of the refrigerant is determined via pressures and temperatures of the refrigerant. The specific enthalpy of the refrigerant entering the evaporator is determined from the pressure and temperature of the liquid supply line. The specific enthalpy of the refrigerant exiting the evaporator is determined via pressure and temperature of the suction line. The enthalpy increase equals the difference in specific enthalpy of evaporator inlet and outlet. Mass flow rate multiplied by enthalpy increase equals heat extraction:

$$Q_{ref} = m_{ref} \cdot \Delta h_{ref}$$

The heat extraction is then converted to electrical energy consumption using the formula below:

$$REC = Q_{tot} * \frac{(308{,}15 - T_{mrun})}{(0{,}34 * T_{mrun})}$$

Q_{tot} is the total heat extracted during the period. T_{mrun} is the evaporation temperature.

The total electrical energy consumption is determined by adding DEC and REC.

Rail heat and defrost cause temperature increase both in cooled products and air of the cabinet. An extra benefit of the adaptive control is lower mean temperature of the products.

During the performance test, temperatures in the cabinet will be measured according to ISO 23953. The cabinet will be equipped with temperature sensors measuring both test packages and air temperature of the cabinet. Data from these sensors will verify the reduced mean temperature of the products.

7.2 Reference analysis

No references are used for this verification process.

7.3 Data management

Data storage, transfer and control must be done in accordance with the requirements of the ETV Quality manual enabling full control and retrieval of documents and records.

7.4 Quality assurance

The quality assurance of the tests must include control of the test system and control of the data quality and integrity.

The test plan and the test report will be subject to review by the expert group as part of the review of this verification protocol and the verification report, see figure 2.

7.5 Test report

The test report must follow the template of the TI verification Center Quality Manual /1/ with data and records from the tests presented.

8 Evaluation

The evaluation includes calculation of the performance parameters, see chapter 5.4 for definition, evaluation of the data quality based upon the test quality assurance, see chapter 7.4 for requirements, and compilation of the additional parameters as specified in chapter 5.5.

8.1 Calculation of performance parameters

All the parameters of interest are analyzed and performance parameters with and without adaptive control are compared to calculate the effect of the product.

8.2 Evaluation of test data quality

The test report must follow the template of the TI Verification Center Quality Manual /1/.

8.3 Compilation of additional parameters

8.3.1 User manual

The manual shall include information on the system description. In particular, it should bear instructions for:

- Operation of the system
- Prevention of and dealing with incidents
- Occupational health and safety measures
- Service and maintenance
- Surveillance of the installation

8.3.2 Occupational health and environment

Machinery for cooling systems must comply with the Machinery Directive /3/. They must be designed and constructed in such a way that they can be used, adjusted and maintained throughout all phases of their life without putting persons at risk.

In detail the installations must satisfy the essential safety requirements contained in Annex I of the Directive, a correct conformity assessment must be carried out and a "Declaration of Conformity" must be given.

It is the responsibility of the manufacturer, importer or end supplier of the equipment to ensure that equipment supplied is in conformity with the Directive. In addition, Council Directive 89/655/EEC of 30 November 1989 /4/ places obligations on businesses and employers to take into account potential dangers to operators and other persons using or affected by machines and equipment.

In general terms, the directive requires that all equipment provided for use at work is:

Suitable for the intended use; safe for use, maintained in a safe condition and, in certain circumstances, inspected to ensure this remains the case; used only by people who have received adequate information, instruction and training; and accompanied by suitable safety measures, e.g. protective devices, markings, warnings.

In addition, ISO 12100-2:2003 /4/ defines technical principles to help designers in achieving safety in the design of machinery.

The safety instructions must be documented for example in a safety data sheet and must be observed carefully.

9 Verification schedule

The verification is planned for 2009. The overall schedule is given in Table 2.

Table 2 - Verification schedule

Task	Timing
Application definition document	May 2009
Verification protocol with test plan	July 2009
Test	Oct. 2009
Test reporting	Nov. 2009
Verification	Nov. 2009
Verification report	Nov. 2009
Verification statement	Dec. 2009

10 Quality assurance

The test protocol, test plan, test report and verification report will be reviewed by internal and external experts according to the Quality plan for the verification, see table 3.

Table 3 - QA plan for the verification

Reviewers	TI	Experts
Plan document with application definition, verification protocol and test plan	ANMD	BE
Report document with test report and verification report	ANMD	BE

Reviews will be done using the TI review report template.

Appendix 1 Terms and definitions used in the verification protocol

Terms and definitions used in the protocol are explained in Table 1:

Table 1 - Terms and definitions used by the DANETV test centers

Word	**DANETV**	**Comments on the DANETV approach**
Analytical laboratory	Independent analytical laboratory used to analyse test samples	The test center may use an analytical laboratory as subcontractor
Application	The use of a product specified with respect to matrix, target, effect and limitations	The application must be defined with a precision that allows the user of a product verification to judge whether his needs are comparable to the verification conditions
DANETV	Danish center for verification of environmental technologies	None
(DANETV) test center	Preliminary name for the verification bodies in DANETV with a verification and a test sub-body	Name will be changed, when the final nomenclature in the EU ETV has been set.
Effect	The way the target is affected	The effect could be reduced energy consumption, better cooling performance etc.
(Environmental) product	Ready to market or prototype stage product, process, system or service based upon an environmental technology	The product is the item produced and sold and thus the item that a vendor submit for verification
Environmental technology	The practical application of knowledge in the environmental area	The term technology is covering a variety of products, processes, systems and services.
Evaluation	Evaluation of test data for a technology product for performance and data quality	None
Experts	Independent persons qualified on a technology in verification	These experts may be technical experts, QA experts for other ETV systems or regulatory

Word	DANETV	Comments on the DANETV approach
		experts
Matrix	The type of material that the product is intended for	Matrices could be cooling systems, cabinets, heat exchangers etc.
Method	Generic document that provides rules, guidelines or characteristics for tests or analysis	An in-house method may be used in the absence of a standard, if prepared in compliance with the format and contents required for standards.
Performance claim	The effects foreseen by the vendor on the target (s) in the matrix of intended use	None
Performance parameters	Parameters that can be documented quantitatively in tests and that provide the relevant information on the performance of an environmental technology product	The performance parameters must be established considering the application(s) of the product, the requirements of society (regulations), customers (needs) and vendor claims
Procedure	Detailed description of the use of a standard or a method within one body	The procedure specifies implementing a standard or a method in terms of e.g.: equipment used
Producer	The party producing the product	None
Standard	Generic document established by consensus and approved by a recognized standardization body that provides rules, guidelines or characteristics for tests or analysis	None
Target	The property that is affected by the product	Targets could be temperature [° C], energy [kWh] etc.
Test center, test sub-body	Sub-body of the test center that plans and performs test	None
Test center, verification sub-body	Sub-body of the test center that plans and performs the verification	None

Word	**DANETV**	**Comments on the DANETV approach**
Test/testing	Determination of the performance of a product for parameters defined for the application	None
Vendor	The party delivering the product to the customer	Can be the producer
Verification	Evaluation of product performance parameters for a specified application under defined conditions and adequate quality assurance	None

Appendix 2 References (verification protocols, requirement documents, standards, methods)

1. DANETV. Center Quality Manual, 2008

2. European Parliament and Council. Directive 2006/42/EC of the 17th May 2006 on machinery and amending Directive 95/16/EC (recast).

3. European Council: Directive 89/655/EEC of 30 November 1989 concerning the minimum safety and health requirements for the use of work equipment by workers at work (amended 2007/30/EC).

4. ISO 12100-2:2003: Safety of machinery - Basic concepts, general principles for design - Part 2: Technical principles

5. European Standard EN ISO 23953 – Refrigerated display cabinets

6. Danish "Design reference year" DRY-data, 1995

7. ISO 13788 – Hygrothermal performance of building components and building elements (Internal humidity loads)

8. Measurement protocol for energy reductions in Refrigerated display cabinets for ETV tests at DANETV

Appendix 3 Application and performance parameter definitions

This appendix defines the application and the relevant performance parameters application as input for verification and test of an environmental technology following the DANETV method.

A3.1 Applications

A3.1.1 Matrix/matrices

- The matrix of the application is freezing/cooling cabinets in retail stores.

A3.1.2 Target(s)

- The target of the product is:
  - Optimized control of rail heat and defrost sessions
  - The power of the rail heat system will adapt according to the surrounding air temperature and humidity and keep the rail temperature a few degrees above the dew point at all time.
  - Frost formations are monitored and the system will only initiate defrost sessions when needed.

A3.1.3 Effects

- The effects claimed by the vendor are presented in table 2:

Table 2 - Performance parameters and vendor claims

Performance parameter	**Vendor claim of performance**
Reduction of energy consumption	15 % reduction of overall energy consumption
No increase in temperature of cooled products	Mean and maximum temperature of cooled are not increased as a side effect of the product
No increase in water vapor condensation	Water vapor condensation is not increased as a side effect of the product